NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1456

PERFORMANCE TESTS OF WIRE STRAIN GAGES

VI - EFFECT OF TEMPERATURE ON CALIBRATION FACTOR AND GAGE RESISTANCE

By William R. Campbell

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SUMMARY

Results of tests to determine the variation in calibration factor and gage resistance with temperature are presented for 15 types of single-element, multistrand wire strain gage.

The maximum difference between the calibration factors for gages of a given type at temperatures between -73° and 93° C and the factor at room temperature did not exceed 4 percent for 13 of 15 types of gage tested. The calibration factor decreased or remained constant with increasing temperature for all but two types of gage, which showed an increase.

Measurements of unit change in gage resistance for temperatures between -73° and 93° C on gages attached to unstressed steel and aluminum-alloy bars indicated a scatter in gage output $\Delta R/R$ for 10 gages of a given type which did not exceed 10×10^{-6} per degree centigrade. This was observed for 12 of the 14 types of gage for which measurements were made. Gages having calibration factors near 2.0 connected in adjacent arms of a Wheatstone bridge could therefore be expected to show an apparent strain with changing temperature of not more than 5×10^{-6} per degree centigrade resulting from lack of perfect temperature compensation between test and dummy gages.

INTRODUCTION

The present report describes one of a series of performance tests on wire strain gages of types currently used in large numbers to measure stresses in aircraft structures. The purpose of the tests is to make available information on the properties, the accuracy, and the limitations of various multistrand, single-element gages.

The performance test program has been divided into several phases the results of which are being reported individually. The first five phases of the program have been reported in references 1 to 5. The present paper reports on the sixth and final phase, the effect of temperature on calibration factor and gage resistance.

This investigation, conducted at the National Bureau of Standards, was sponsored by and conducted with the financial assistance of the National Advisory Committee for Aeronautics.

The author desires to acknowledge the cooperation of the NACA Ames Aeronautical Laboratory, the Baldwin Locomotive Works, the Boeing Aircraft Company, the Chrysler Corporation, the Consolidated Vultee Aircraft Corporation, the Douglas Aircraft Company, the Lockheed Aircraft Corporation, North American Aviation Incorporated, and Northrop Aircraft Incorporated, in submitting gages. The author is indebted to Mr. A. F. Medbery and Mrs. June O. Montgomery of the Engineering Mechanics section of the National Bureau of Standards for assistance on the test program.

SYMBOLS

E	Young's modulus of elasticity, pounds per square inch
K	calibration factor of wire strain gage, ohms per ohm per inch per inch
ΔP	change in load P
$\Delta R/R$	unit change in gage resistance R
t	temperature, $^{\circ}C$
Δt	change in temperature, $^{\circ}C$
α	thermal coefficient of linear expansion/$^{\circ}C$
β	thermal coefficient of Young's modulus/$^{\circ}C$
$\Delta\epsilon$	change in strain

DESCRIPTION OF STRAIN GAGES

Six aircraft companies, the NACA Ames Aeronautical Laboratory, the Baldwin Locomotive Works, and the Chrysler Corporation contributed gages of 15 different types (A, ...,G,H-1, I...,O). These gages are identical with the gage types described in table 1 and figures 1 and 2 of reference 1, with the exception of gage type H-1 which was substituted by the maker for gage type H. Data on gage type H-1 are given in appendix I of reference 2.

TESTS

Tests were made on two gages of each type to determine the variation in calibration factor with temperature for temperatures between -73° C (-100° F) and 93° C (200° F).

Measurements of unit change in gage resistance $\Delta R/R$ with temperature were made for gages of each type attached to unstressed bars of 24S-T aluminum alloy ($\alpha = 21.3 \times 10^{-6}/^\circ C$) and cold-rolled steel ($\alpha = 11.3 \times 10^{-6}/^\circ C$). Ten gages of a given type were tested on each of the two materials at temperatures between -73° and 93° C to provide data on several gages of the same type and to show the influence of the coefficient of thermal expansion α of the "structure" on gage output.

APPARATUS AND PROCEDURE

The calibration factor K_t of a wire strain gage is given by the following equation in which the unit change in gage resistance $\Delta R/R$ and the corresponding change in strain $\Delta\epsilon$ are experimentally determined:

$$K_t = \left(\frac{\Delta R}{R}\right)_t \frac{1}{(\Delta\epsilon)_t} \tag{1}$$

A known change in strain was produced as follows. A relatively long and flexible calibration bar was so arranged that the bar could be axially loaded with dead weights, and the gages were attached to the center section of the bar which could be subjected to variable temperature. A strain change $\Delta\epsilon_t$ was then obtained by loading and unloading the bar with a constant load P. The ratio of the calibration factor K_t at a temperature t to that at room temperature (30° C) is then given by

$$\frac{K_t}{K_{30}} = \frac{(\Delta R/R)_t}{(\Delta R/R)_{30}} \frac{(\Delta\epsilon)_{30}}{(\Delta\epsilon)_t} \tag{2}$$

The change in strain $\Delta\epsilon_t$ must be corrected for the increase in cross-sectional area by a factor $(1 + \alpha\,\Delta t)^2$ because of the thermal expansion of the material for a change in temperature $\Delta t = t - 30$, and it must be corrected for the change in Young's modulus with temperature by a factor $(1 + \beta\,\Delta t)$. With these corrections equation (2) becomes

$$\frac{K_t}{K_{30}} = \frac{(\Delta R/R)_t}{(\Delta R/R)_{30}} (1 + \alpha \Delta t)^2 (1 + \beta \Delta t) \tag{3}$$

Equation (3) was used to compute the change in calibration factor with temperature for all gages. An average value of $\alpha = 2.2 \times 10^{-5}$ per degree centigrade was assumed for the calibration bar of 24S-T aluminum alloy. The maximum value of the term $(1 + \alpha \Delta t)^2$ in equation (3) differed less than 0.5 percent from unity; hence a precise determination of α was not considered necessary. The thermal coefficient of Young's modulus of elasticity β for the temperature range -50° to 50° C of an alloy almost identical in composition with 24S aluminum alloy is given by Keulegan and Houseman (reference 6, p. 305, table 3, Duralumin) as $\beta = -58.3 \times 10^{-5}$ per degree centigrade. A rough value of β was determined from measurements of a natural frequency at temperatures between -73° and 93° C of a 24S-T aluminum alloy cantilever beam. This gave $\beta = -62.4 \times 10^{-5}$ per degree centigrade. Keulegan's value of $\beta = -58.3 \times 10^{-5}$ per degree centigrade, which was determined with considerable care, was therefore regarded as adequate for substitution in equation (3). The maximum value of the term $(1 + \beta \Delta t)$ in equation (3) differed less than 6 percent from unity. A more exact determination of β was therefore deemed unnecessary.

The test setup is shown in figure 1. The calibration bar upon which gages were attached was a 4-foot strip A of 24S-T aluminum alloy having 0.50- by 0.025-inch cross section. A similar strip B was used for mounting temperature-compensating gages. Both strips were mounted inside a temperature cabinet C so that the central portions of the strips, where gages were attached, were in the temperature-controlled region of the cabinet and the ends of the strips projected through openings in the top and the bottom of the cabinet. The temperature-compensating strip was clamped at the upper end and was free at the lower end. The ends of the loaded strip were held in Templin grips, the upper grip D being fastened to a crane hook and the lower grip attached to a tray for holding dead weights E. The dead-weight load of 150 pounds, corresponding to $\Delta\epsilon = 11.3 \times 10^{-4}$, could be applied and removed by lowering and raising a platform F. The weight of the tray and of the lower grip was sufficient to hold the calibration strip in alinement at the initial load. It was found that six to eight gages could be calibrated during one temperature cycle. One gage of each type was attached to the loaded strip and one to the compensating strip. Test and compensating gages of the same type were located in similar positions on the two strips for optimum temperature compensation. Leads were brought out of the cabinet for each gage and the test and compensating gages of a given type were connected to an SR-4 portable strain indicator G (reference 7). The balance reading on the indicator was recorded with and without the dead-weight load on the test strip. The difference between the two balance readings was multiplied by the gage factor setting on the indicator (for convenience set at 2.00 for all gages) to obtain $(\Delta R/R)$ for the gage.

Tests were started by setting the cabinet thermostat at 93° C in the evening and the cabinet heaters were kept on all night, since it required about 6 hours to reach 93° C from room temperature. This procedure allowed the gages about 15 hours additional drying time after drying 2 days at room temperature. The output of each gage due to the change in load ΔP was then determined at 93° C after the strip had been overloaded several times with an additional 10 pounds to reduce zero shift and improve linearity. Individual loading cycles, requiring about 1 minute, were made for each gage. Similar tests were repeated at other temperatures down to -73° C. The ratio of the calibration factor at a temperature t to the calibration factor at room temperature was computed for each gage by substituting the measured unit changes in gage resistance $(\Delta R/R)_t$, at the different temperatures, in equation (3). Following this temperature cycle, the tests were repeated with new gages. Two gages of each type were calibrated.

The measurements of calibration-factor ratios were followed by measurements of $\Delta R/R$ with gages attached to unstressed specimens subjected to changing temperature. The measurements were made on 20 gages of each type. Ten gages were attached to an 18- by 1- by 0.125-inch bar of 24S-T aluminum alloy, and ten were attached to a similar bar of cold-rolled steel. These bars were then suspended in the temperature cabinet A (fig. 2) in which the temperature was varied from -73° to 93° C. Leads were brought out from each gage for connection to an SR-4 portable strain indicator B used to measure $\Delta R/R$. A resistance decade box C, set at the nominal gage resistance, was connected to the SR-4 indicator in place of the usual compensating gage. During the temperature cycle the decade was not changed and the unit change in gage resistance $\Delta R/R$ was taken as the product of the change in the indicator dial reading and the gage factor setting on the indicator, which for convenience was set at 2.00. This procedure was modified in the case of gage N because of the extreme sensitivity of this gage to temperature. The SR-4 indicator for gages of type N was set at midscale and the bridge was balanced by changing the decade resistance in 0.1-ohm steps. Then $\Delta R/R$ was computed directly from the change in the original decade reading.

RESULTS AND DISCUSSION

Values of K_t/K_{30} are plotted against temperature in figures 3 to 6. The scatter in gage output $\Delta R/R$ per degree centigrade for 10 gages of a given type attached to the steel and aluminum-alloy bars is given in table 1.

Curves of gage output $\Delta R/R$ against temperature are given in figures 7 to 20 for all gages except those of type G, which were not available. Three curves, corresponding to the maximum, minimum, and average gage output for 10 gages of a given type, are plotted for each of the two materials upon which the gages were attached.

Inspection of figures 3 to 6 shows that within the scatter of measurement the calibration factor for gages of types A, C, D, F, H-1, I, K, and N did not vary more than 2 percent from the room-temperature value for temperatures between -73° and 93° C. It should be noted that the measured changes in calibration factor include any creep in the bonding cement which may have occurred during the loading cycle. Since creep is a function of time, it is possible that changes in calibration factor of a different magnitude may result with loading cycles of different duration.

Gages of types B and E showed a decrease in calibration factor with increasing temperature of about 1 percent for each 30° C change in temperature. The calibration factors differed from the room-temperature values by no more than 4 percent, however, for the temperature range considered. Gages B and E were of different manufacture but both were attached with the same cement (General Service). This fact suggests that the measured variations in calibration factor may have been caused by a variation in elastic properties with temperature of the cement common to these two types of gage.

Gages of types J and O showed an increase in calibration factor with temperature of about 1 percent for each 30° C rise in temperature. These gages differed only in resistance. They were of identical construction and were both attached with the same cement (celluloid ethyl acetate); hence they may be expected to show similar characteristics. Since it is unlikely that the efficiency with which cellulose cements transfer strain to strain-sensitive wire improves with increasing temperature, it is probable that the increase in calibration factor is due to sources other than the cement. There was no obvious cause to which the phenomenon could be ascribed.

Gages of type M showed a decrease in calibration factor of about 1 percent for each 40° C rise in temperature. This gage is of the "wrap-around" construction and was attached with Duco cement. Although Duco cement retained its strength in the case of gages of types A, C, D, F, H-1, I, K, and N which were attached with this cement, it is believed that the greater shear loads on the cement imposed by the greater wire density in the wrap-around winding increases the creep rate over that of other gages.

Gages of type G showed somewhat erratic performance in these tests just as in previous tests (references 1 to 5). Some of the values for K_t/K_{30} (fig. 4) scattered by as much as ±6 percent. The scatter was too great to indicate any consistent variation of calibration factor with temperature.

The largest change in calibration factor was found for gages of type L. For these gages the calibration factor was down more than 5 percent at 93° C as compared with 30° C, and it was up more than 3 percent at -73° C.

Examination of table 1 shows that the scatter in gage output $\Delta R/R$ for 10 gages of a given type attached to the bar of cold-rolled steel ranged from 1.2×10^{-6} per degree centigrade for gages D to 14.9×10^{-6} per degree centigrade for gages K. The corresponding scatter for 10 gages attached to the aluminum-alloy bar ranged from 1.1×10^{-6} per degree centigrade for gages F to 34.6×10^{-6} per degree centigrade for gages K.

The curves in figures 7 to 20 show that the change in gage resistance with temperature is nonlinear for most gages.

The difference in $\Delta R/R$ with changing temperature between gages attached to the steel and to the aluminum-alloy bars may be ascribed to the difference in thermal expansion coefficients of the two bars. This was checked by subtracting from the measured average output given in the figures, the quantity $K\alpha\,\Delta t$ $(\Delta t = t + 73^{\circ})$ which corresponds to the thermal expansion of the calibration bar. The resulting two curves are shown dotted in the figures. They should, theoretically, coincide since both correspond to the output of the gage when attached to a material with a thermal expansion coefficient $\alpha = 0$. Examination of the dotted curves in figures 7 to 20 shows that they do coincide within the scatter of the experimental data.

A further check was obtained for gages D and F (figs. 10 and 12, respectively) by direct measurement of $\Delta R/R$ with gages of these types attached to fused quartz as shown in figure 21. The coefficient of expansion of fused quartz, $\alpha = 0.4 \times 10^{-6}$ per degree centigrade, is so close to zero that the curve of output against temperature should approach that given by the dotted curves for $\alpha = 0$. Inspection of figures 10 and 12 shows that this actually was the case.

The dotted curves may be utilized for estimating the output when the gage is attached to any material with known expansion coefficient α. The output is given by adding $K\alpha\,\Delta t$ to the ordinate of the dotted curve.

Incidentally, the fact that the dotted curves are in close agreement may be regarded as a check on the previous result that the calibration factor K is nearly independent of temperature.

CONCLUSIONS

Calibrations of gages at temperatures between -73° and 93° C showed that the calibration factors of more than half of the 15 types of gage tested were relatively insensitive to changes in temperature. The calibration factor for all but two types of gage differed from the factor at room temperature by no more than 4 percent for temperatures between -73° and 93° C.

Measurements of unit change in gage resistance with temperature for gages attached to unstressed bars showed that the scatter in output $\Delta R/R$ between gages of the same type did not exceed 10×10^{-6} per degree centigrade for 12 of the 14 types of gage. Gages having calibration factors near 2.0 connected in adjacent arms of a Wheatstone bridge could therefore be expected to show an apparent strain with changing temperature which did not exceed about 5×10^{-6} per degree centigrade because of lack of perfect compensation between test and dummy gages.

National Bureau of Standards
Washington, D. C., September 4, 1946

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6. Keulegan, G. H., and Houseman, M. R.: Temperature Coefficient of the Moduli of Metals and Alloys Used as Elastic Elements. Res. Paper 531, Nat. Bur. of Standards Jour. Res., vol. 10, no. 1, March 1933, pp. 290-320.

7. Anon. SR-4 Portable Strain Indicator. Bull. 169, Baldwin Locomotive Works, Baldwin Southwark Div. (Philadelphia), 1942.

TABLE 1. SCATTER IN GAGE OUTPUT $\Delta R/R$ PER DEGREE CHANGE IN TEMPERATURE FOR 10 GAGES ATTACHED TO UNSTRESSED STEEL AND DURALUMIN SPECIMENS

Cold-rolled steel		24S-T aluminum alloy	
Gage type	$\frac{\Delta R}{R}/{}^{o}C$ (1)	Gage type	$\frac{\Delta R}{R}/{}^{o}C$ (1)
D	1.2×10^{-6}	F	1.1×10^{-6}
F	1.4	A	1.2
H-1	1.6	H-1	1.6
J	1.7	M	1.9
I	2.0	I	2.3
E	2.4	L	3.3
L	2.8	J	3.9
M	2.8	C	5.3
A	3.7	D	5.5
B	4.3	E	6.0
O	6.5	O	8.0
N	9.2	B	9.2
C	11.7	N	9.8
K	14.9	K	34.6

[1]Average values for change in temperature from -73° to 93° C.

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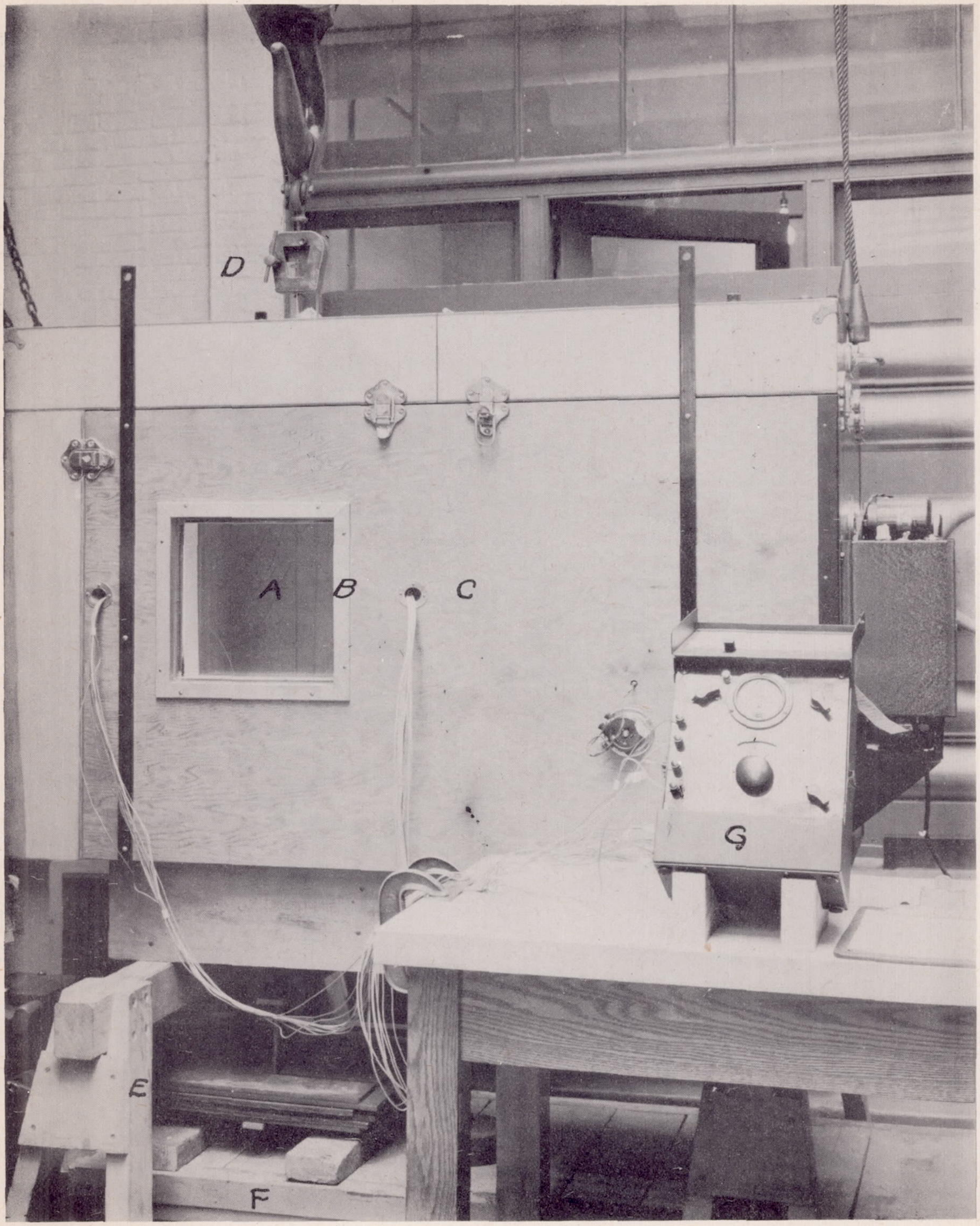

Figure 1.- Test setup.

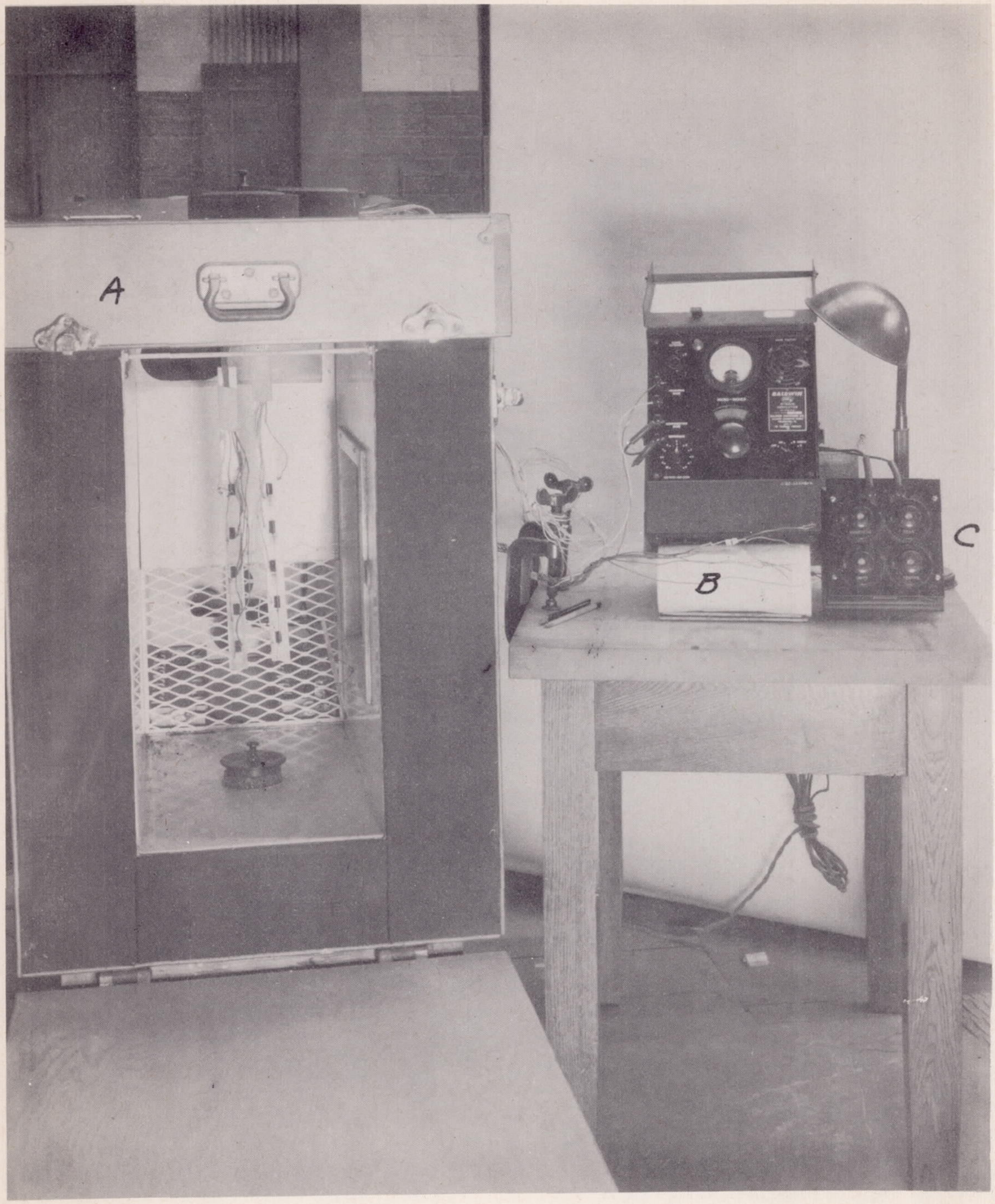

Figure 2.- Temperature cabinet, portable strain indicator, and resistance decade box.

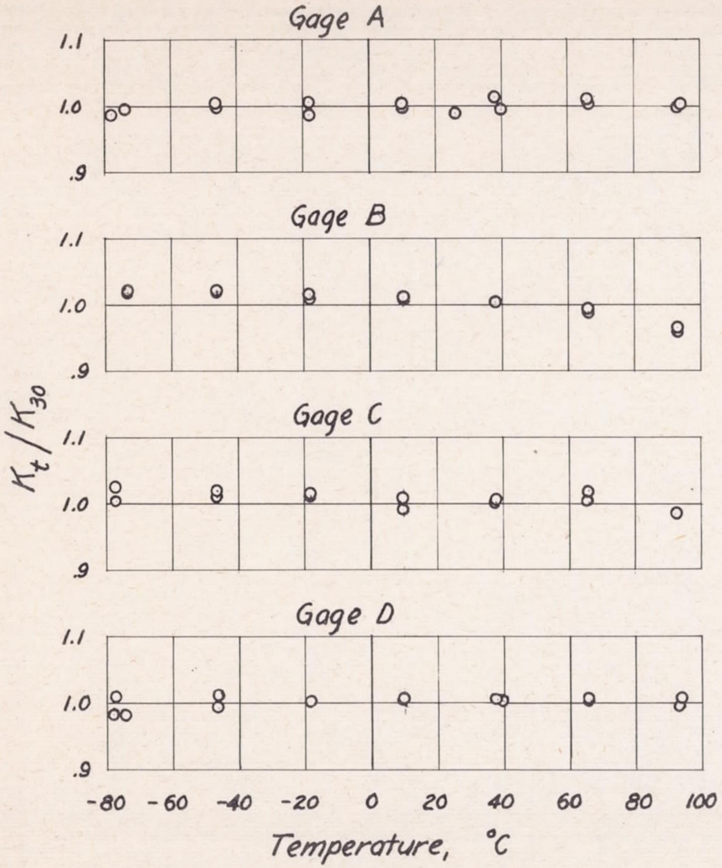

Figure 3.- Variation of K_t/K_{30} with temperature for gages A, B, C, and D.

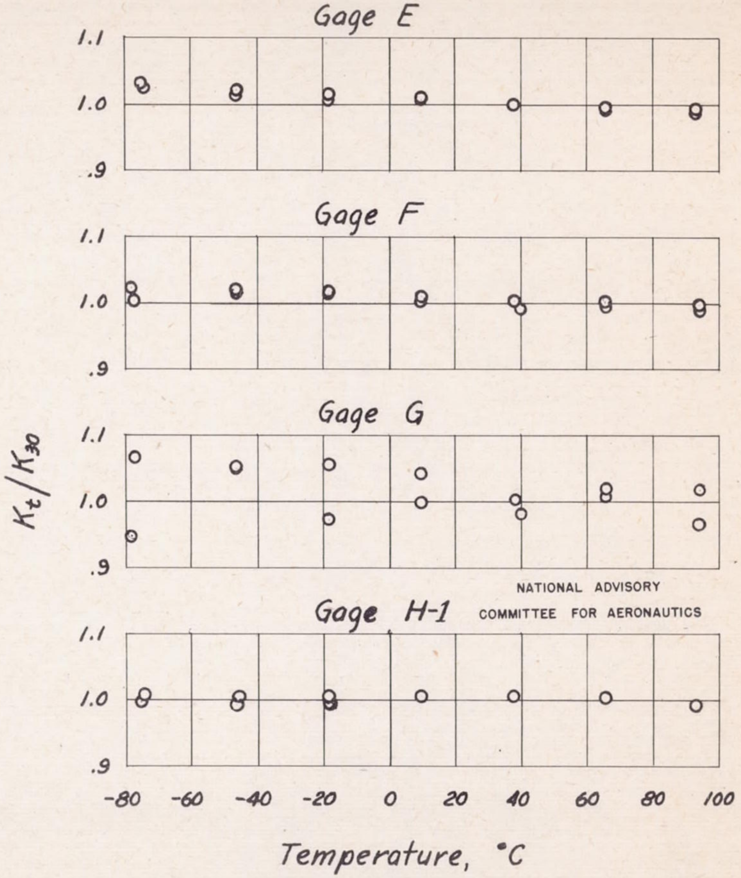

Figure 4.- Variation of K_t/K_{30} with temperature for gages E, F, G, and H-1.

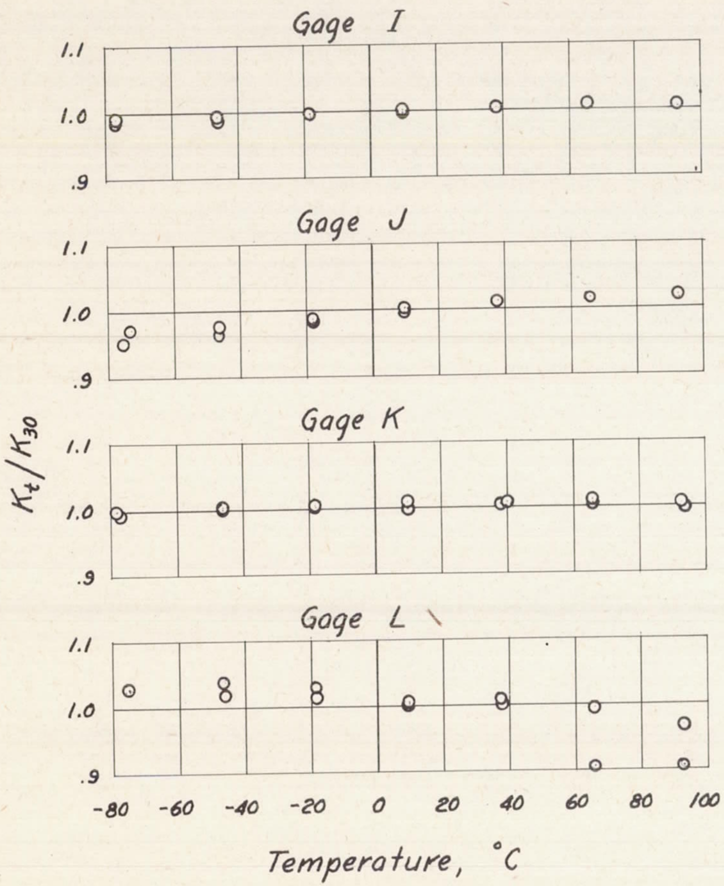

Figure 5.- Variation of K_t/K_{30} with temperature for gages I, J, K, and L.

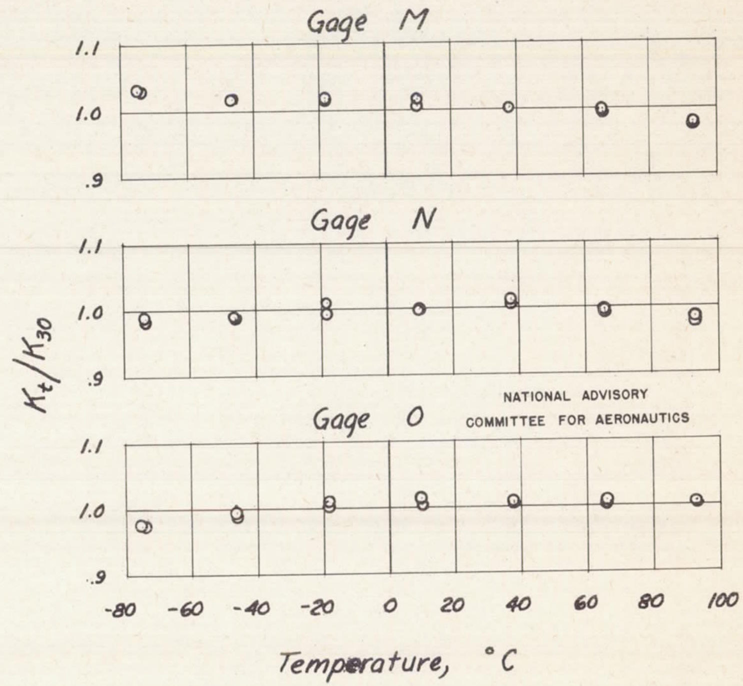

Figure 6.- Variation of K_t/K_{30} with temperature for gages M, N, and O.

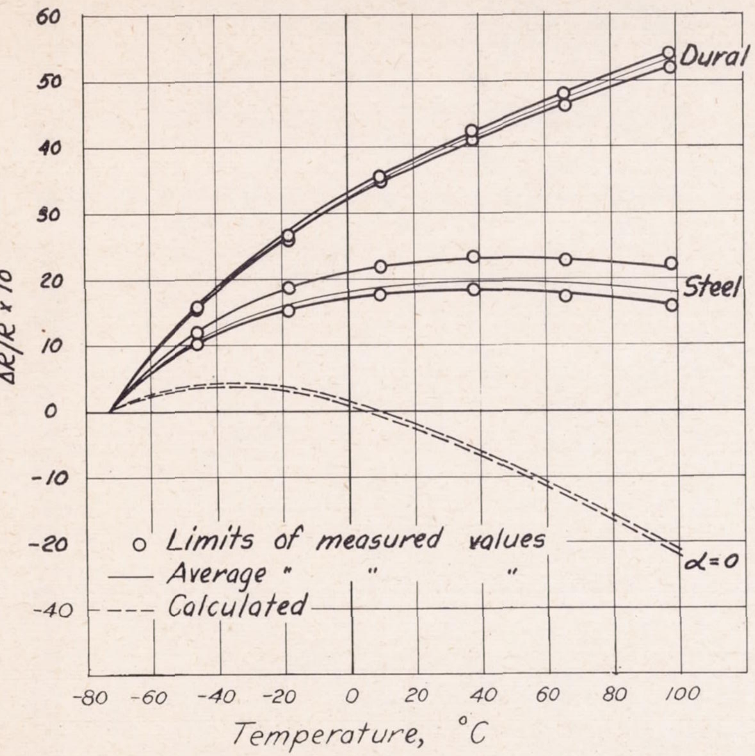

Figure 7.- Variation of gage output $\Delta R/R$ with temperature for gage A.

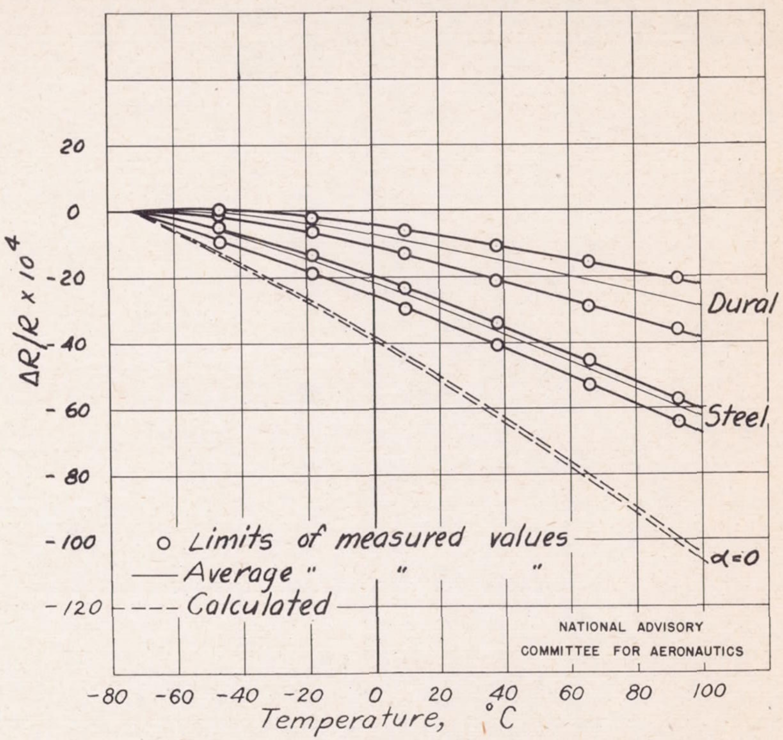

Figure 8.- Variation of gage output $\Delta R/R$ with temperature for gage B.

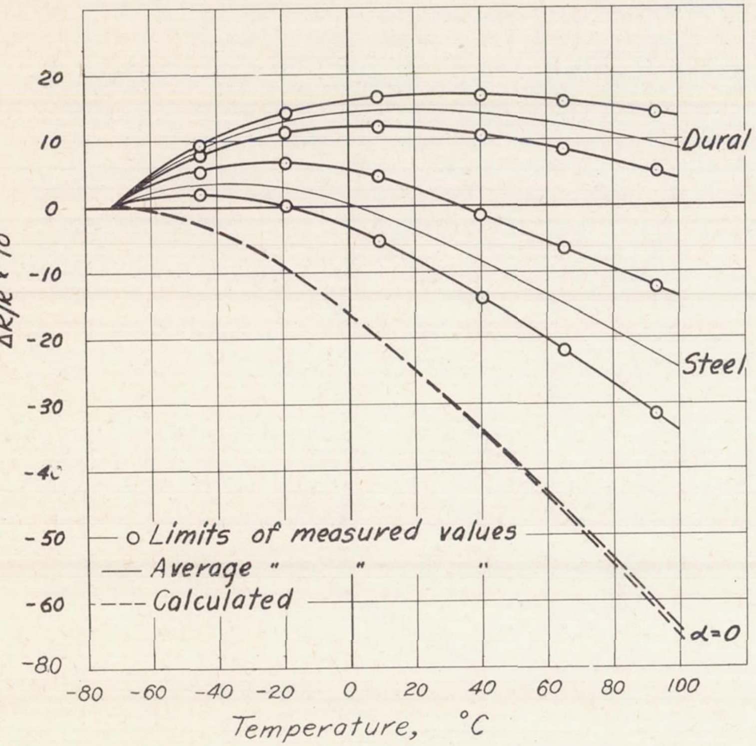

Figure 9.- Variation of gage output $\Delta R/R$ with temperature for gage C.

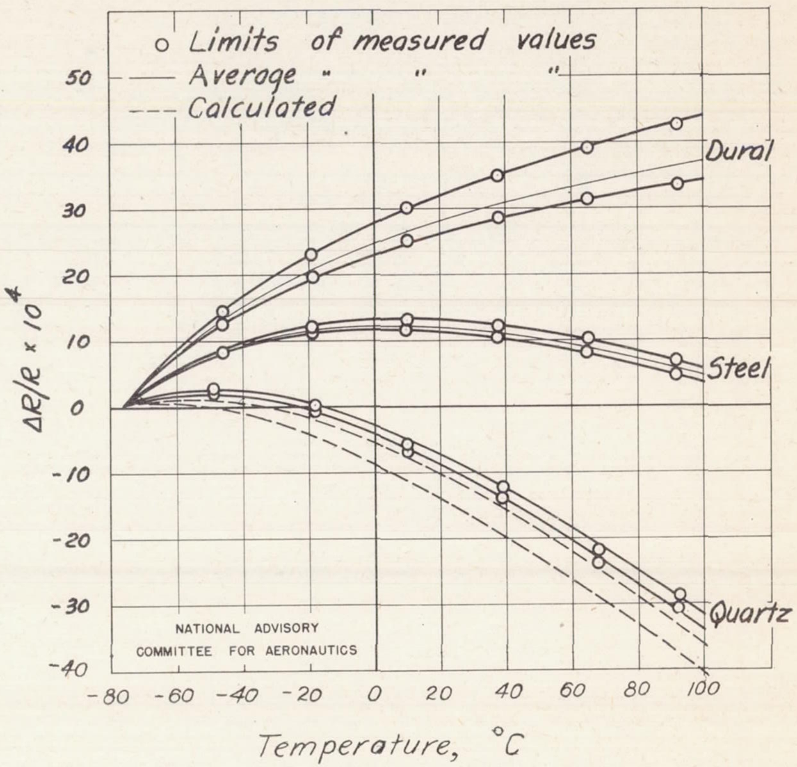

Figure 10.- Variation of gage output $\Delta R/R$ with temperature for gage D.

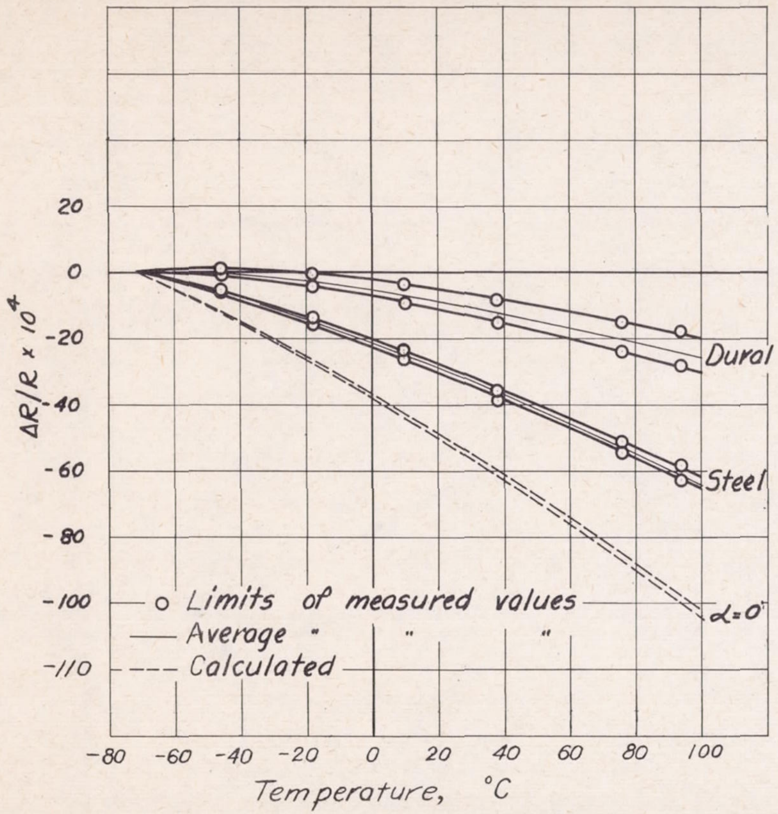

Figure 11.- Variation for gage output $\Delta R/R$ with temperature for gage E.

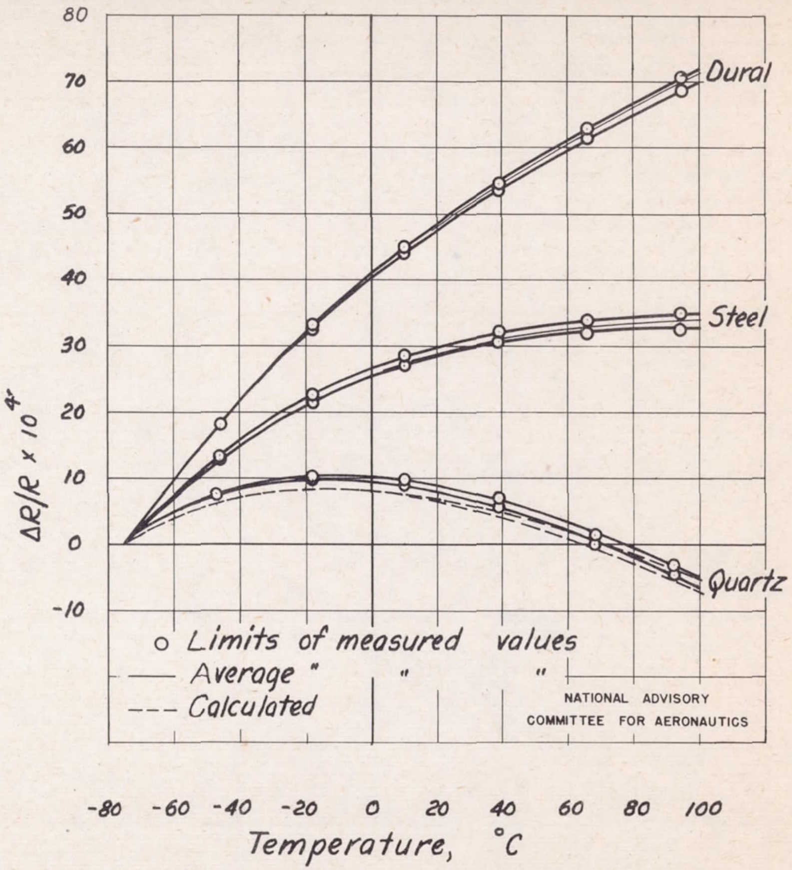

Figure 12.- Variation of gage output $\Delta R/R$ with temperature for gage F.

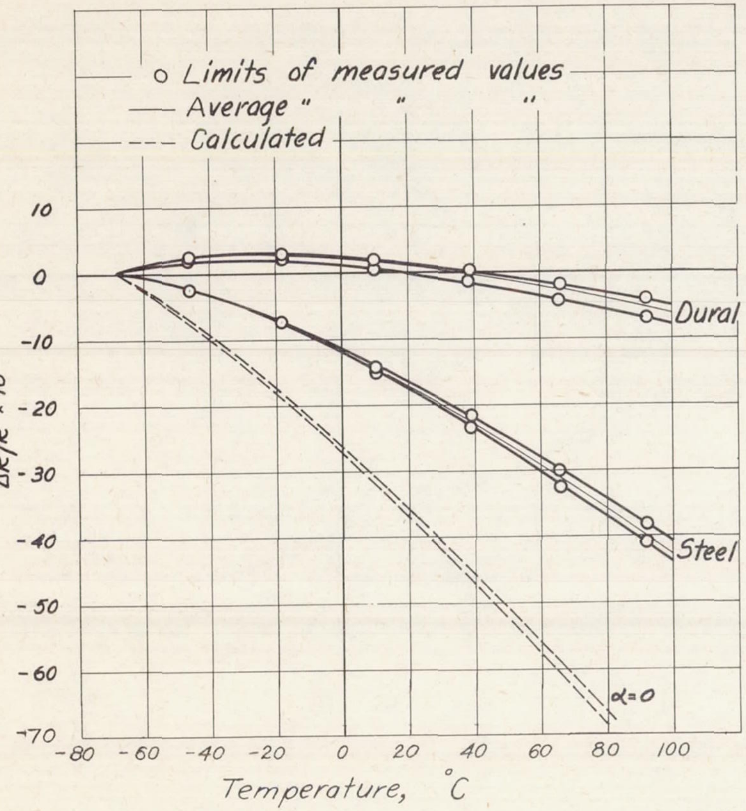

Figure 13.- Variation of gage output $\Delta R/R$ with temperature for gage H-1.

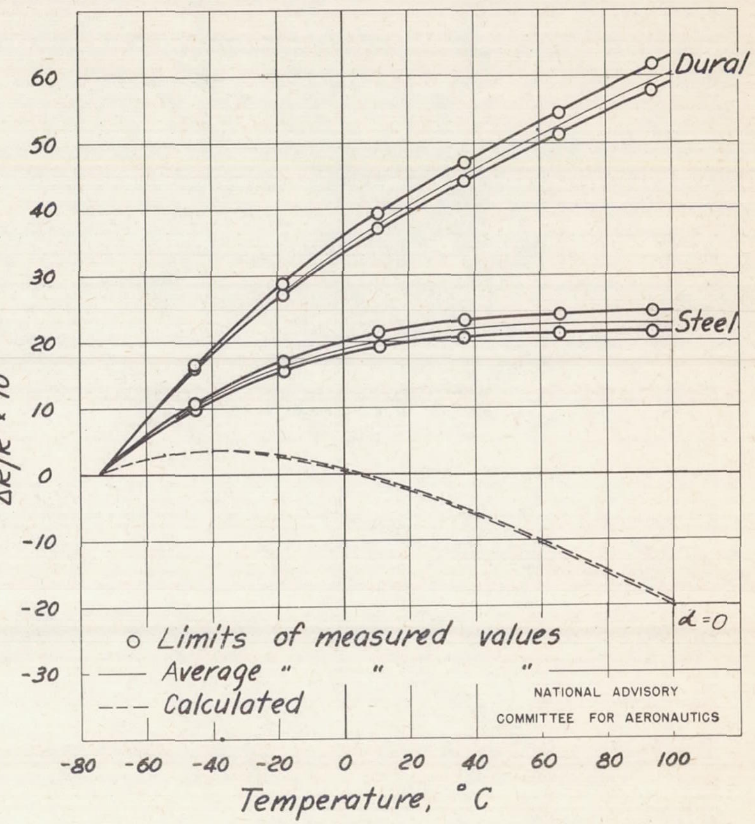

Figure 14.- Variation of gage output $\Delta R/R$ with temperature for gage I.

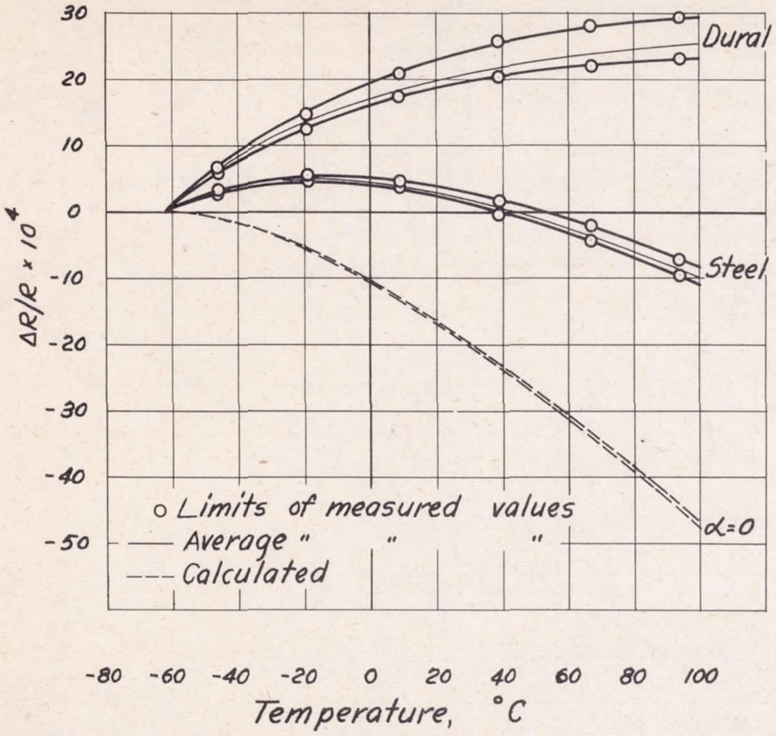

Figure 15.- Variation of gage output $\Delta R/R$ with temperature for gage J.

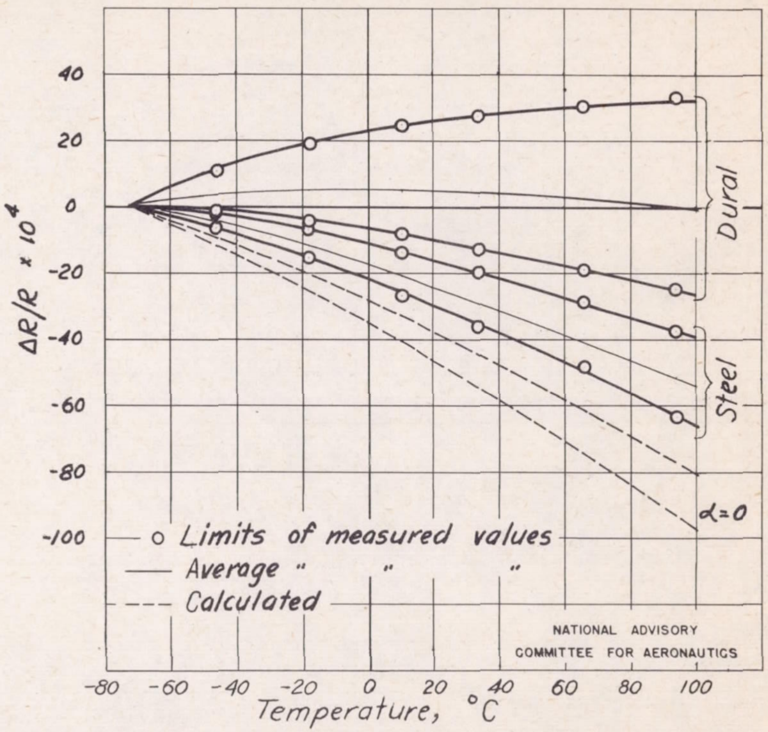

Figure 16.- Variation of gage output $\Delta R/R$ with temperature for gage K.

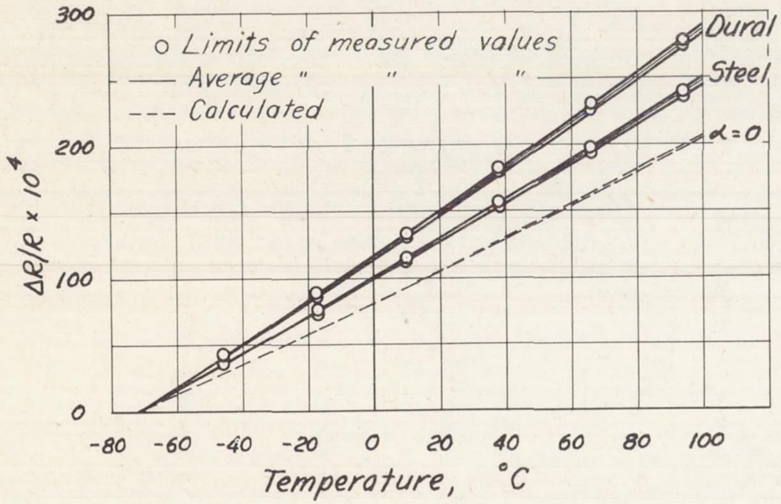

Figure 17.- Variation of gage output $\Delta R/R$ with temperature for gage L.

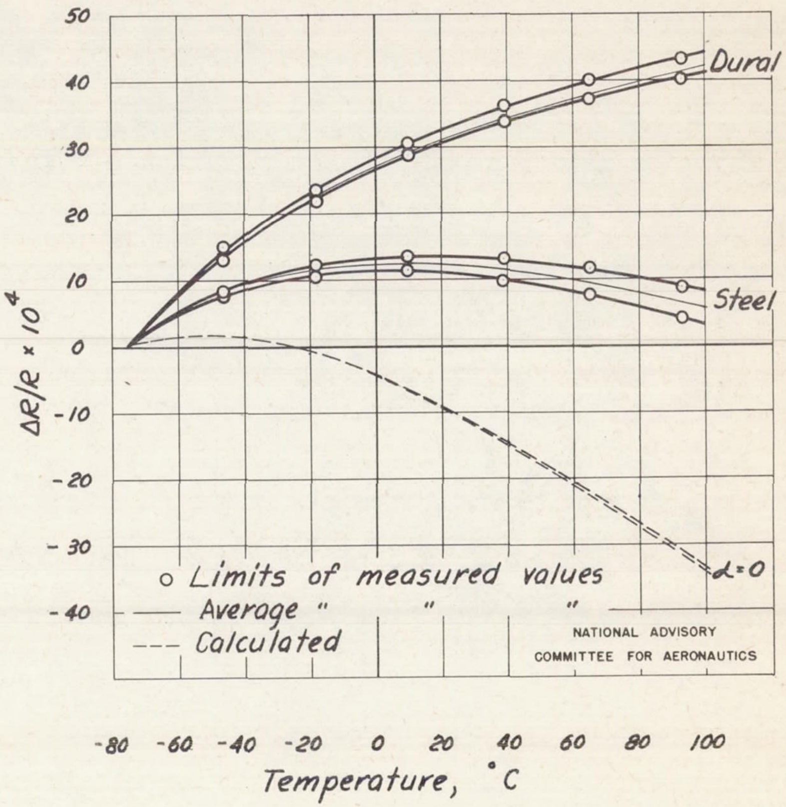

Figure 18.- Variation of gage output $\Delta R/R$ with temperature for gage M.

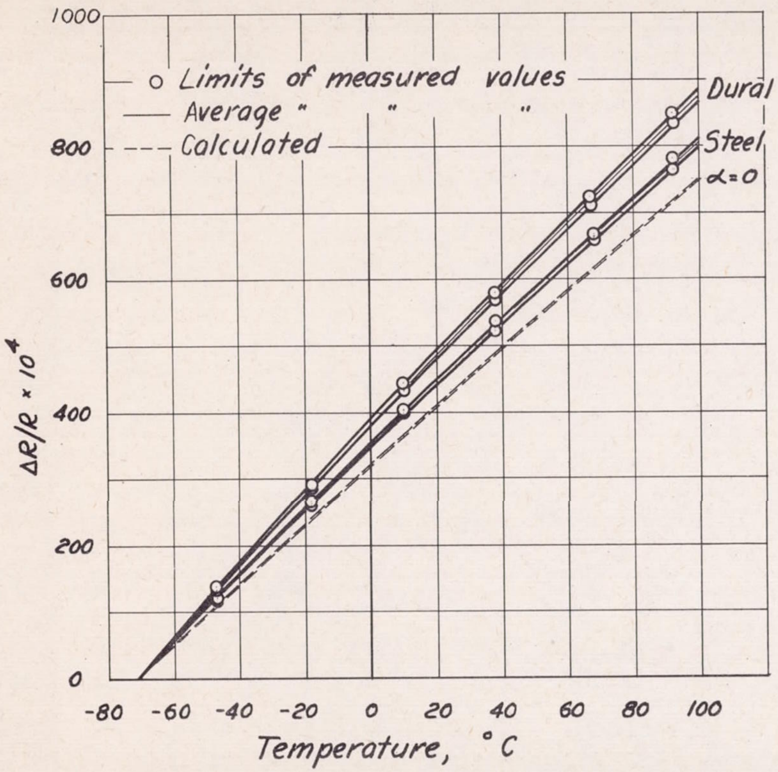

Figure 19.- Variation of gage output $\Delta R/R$ with temperature for gage N.

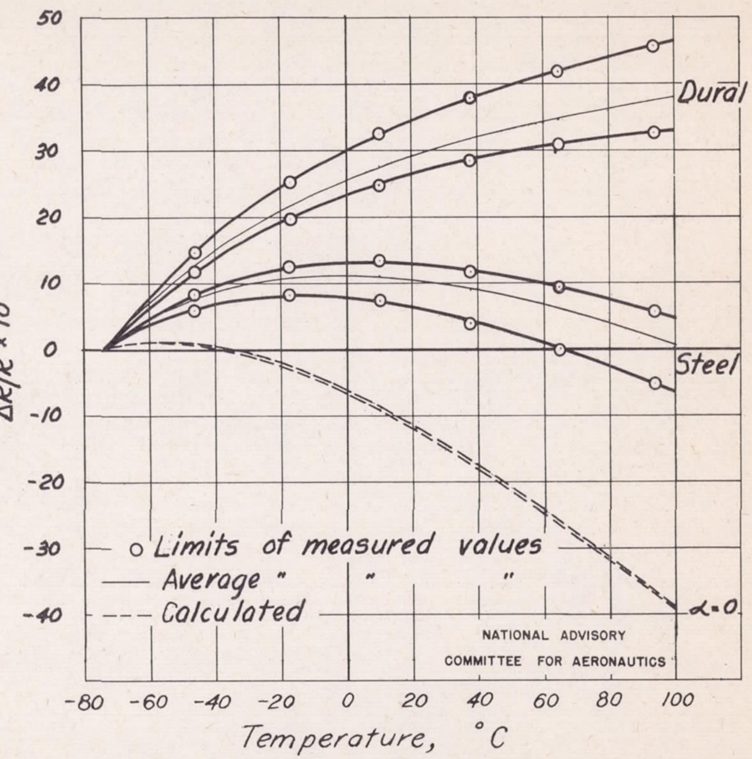

Figure 20.- Variation of gage output $\Delta R/R$ with temperature for gage O.

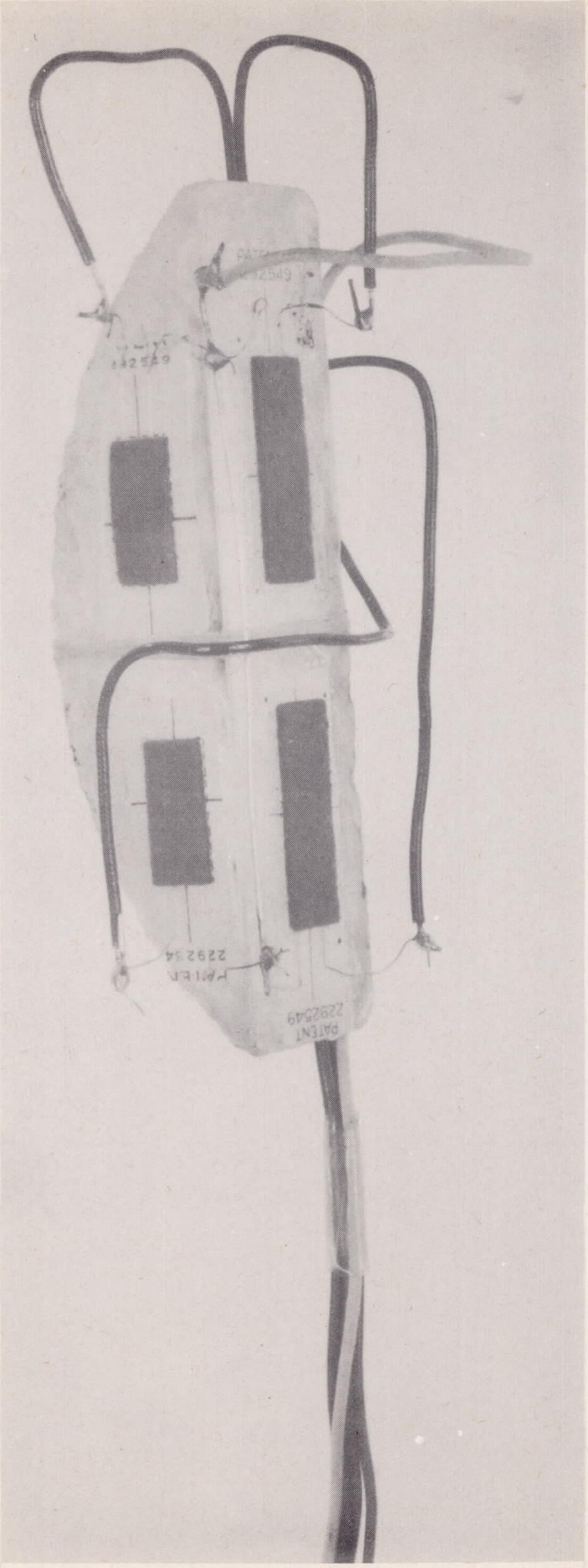

Figure 21.- Gages attached to fused quartz.